ICRF CONSISTENCY CHECK BY COMPARISON OF THE ICRF-Ext.1 WITH THE GAOUA SERIES OF RS CATALOGUES

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ABSTRACT. Main Astronomical Observatory of the National Academy of Sciences of Ukraine (GAOUA is the acronym used by the IERS) is engaged in construction of the ICRF as realized by VLBI. Two different series of catalogues of radio source (RS) positions have been constructed, namely initial catalogues of RSC(GAOUA)YY R NN as resulted from processing the VLBI observations with the SteelBreeze software and combined catalogues of type RSC(GAOUA)YY C NN as resulted from using the so-called Kyiv arc length method for combining initial catalogues provided by various Analysis Centers of the IERS. New initial reference frame RSC(GAOUA)03 R 01 was constructed based on VLBI data from 1979 to 2003 as well as new combined catalogue RSC(GAOUA)03 C 01 was constructed applying the Kyiv arc length method to four initial frames RSC(BKG)03 R 01, RSC(CGS)02 R 01, RSC(GAOUA)03 R 01 and RSC(AUS)03 R 01. Results of comparison between the ICRF-Ext.1, four initial frames, and the combined frame are discussed.

1. INTRODUCTION

Main Astronomical Observatory of the National Academy of Sciences of Ukraine (GAOUA is the acronym used by the IERS) is engaged in construction of the ICRF as realized by VLBI. Two different series of catalogues of radio source (RS) positions have been constructed, namely initial catalogues of RSC(GAOUA)YY R NN as resulted from processing the VLBI observations with the SteelBreeze software and combined catalogues of type RSC(GAOUA)YY C NN as resulted from using the so-called Kyiv arc length method for combining initial catalogues provided by various Analysis Centers of the IERS or the IVS. These catalogues have been used for check of consistency of the ICRF.

2. GAOUA INITIAL CATALOGUES OF RS POSITIONS

Several initial catalogues have been constructed using various versions of the SteelBreeze software (S. Bolotin, 2001). Table 1 gives overview of the GAOUA initial catalogues.

The recent initial catalogue of RS positions RSC(GAOUA)03 R 01 is based upon a solution for all applicable VLBI data since 1979 till July 2003. In total 3,550,143 dual frequency delays acquired on 2,970 astrometric and geodetic sessions have been processed (S. Bolotin, 2003).

Table 1: Statistics of the GAOUA initial catalogues. N is total number of RS positions; N_d is the number of defining RS; σ is internal r.m.s. uncertainty (in mas).

Frame	N	N_d	$\sigma_\alpha * \cos\delta$	σ_δ	Software version
RSC(GAOUA)96 R 01	160	33	0.14	0.21	SteelBreeze-1.0
RSC(GAOUA)97 R 01	129	17	0.21	0.38	SteelBreeze-1.0
RSC(GAOUA)98 R 01	198	55	0.25	0.41	SteelBreeze-1.0
RSC(GAOUA)00 R 01	191	47	0.22	0.39	SteelBreeze-1.2
RSC(GAOUA)03 R 01	1558	211	0.10	0.13	SteelBreeze-2.0

The initial values of RS positions have been taken from the ICRF-Ext.1. Orientation of constructed reference frame was defined by a No-Net-Rotation condition between the ICRF-Ext.1 and the derived catalogue using 35 defining radio sources.

3. GAOUA COMBINED CATALOGUES OF RS POSITIONS

The Kyiv arc length method proposed by Ya. Yatskiv and A. Kur'yanova, 1990, was used for construction of catalogues of type RSC(GAOUA)YY C NN since 1991. This method combines a geometrical arc length calculation with a statistical evaluation of uncertainties of individual and compiled catalogues. The following items explain essentials of the method approach (corresponding mathematical formulae can be found in Kur'yanova A.N. and Yatskiv Ya.S., 1993):

- selection of "basic" catalogues of radio source (RS) positions from set of individual catalogues;
- search for defining RSs common to each selected "basic" catalogues;
- calculation of arc lengths (below simply "arcs") between defining RSs which are common in all "basic" catalogues;
- comparison of calculated arcs for "basic" catalogues, which resulted in evaluation of catalogue weights; determination of mean values of the arcs and "arc minus mean arc" residuals;
- construction of so-called individual "rigid" frames which are based on the arcs between defining RS and on the systems, defined by positions of two selected RSs;
- construction of combined "rigid" frame using the data of previous steps;
- alignment of this combined "rigid" frame to the ICRF and construction of combined reference frame using No-Net-Rotation condition between the combined frame and the ICRF for common defining RSs;
- extension of the reference frame realized by common defining RSs to additional RSs, involved in process of constructing the combined frame.

The eight combined solutions based upon initial catalogues of RS positions provided by IERS and/or IVS were constructed (Y. Yatskiv, O. Molotaj, A. Kur'yanova and V. Tel'nyuk-Adamchuk, 2003).

Table 2 gives some characteristics of the initial reference frames which have been used for construction of recent combined catalogue RSC(GAOUA)03 C 01. Three frames, namely RSC(BKG)03 R 01, RSC(CGS)02 R 01 and RSC(GAOUA)03 R 01 have been used as individual "basic" frames in process of constructing the compiled catalogue of GAOUA type. RS 1606+106 and RS 1130+009 are selected as "basic" sources for defining "rigid" frames.

Table 2: List of VLBI frames under consideration. N is the number of radio sources in the frame; N_b is the number of defining RSs common for the first three catalogues: σ is internal r.m.s. uncertainty (in mas); W is frame weight used for constructing the "rigid" frame.

Frame	N	N_b	$\sigma_\alpha * cos\delta$	σ_δ	W
RSC(BKG)03 R 01	630	161	0.06	0.08	0.38
RSC(CGS)02 R 01	457	161	0.11	0.13	0.14
RSC(GAOUA)03 R 01	1558	161	0.07	0.09	0.48
RSC(AUS)03 R 01	659	161	0.09	0.16	–
RSC(GAOUA)03 C 01	1667	161	0.06	0.08	–

4. COMPARISON OF THE INITIAL FRAMES WITH RSC(GAOUA)03 C 01 and ICRF-Ext.1

Initial and combined catalogues have been compared by using the IERS model:

$$\begin{aligned} A_1 \tan\delta\cos\alpha + A_2 \tan\delta\sin\alpha - A_3 + D_\alpha(\delta - \delta_\circ) &= \alpha_1 - \alpha_2 \\ -A_1 \sin\alpha + A_2 \cos\alpha + D_\delta(\delta - \delta_\circ) + B_\delta &= \delta_1 - \delta_2, \end{aligned}$$

where A_1, A_2, A_3 are rotation angles between two frames under consideration; D_α, D_δ, B_δ represent the systematic effects by three deformation parameters, namely D_α – drift in right ascension as a function of the declination, D_δ – drift in declination as a function of the declination and B_δ – bias in declination.

Only defining sources which are common in the initial frames, RSC(GAOUA)03 C 01 and ICRF-Ext.1 (RSC(WGRF)99 R 01) were used in comparisons. The transformation parameters were evaluated by a least squares fit without weights. The relative global orientation and the deformation parameters between initial catalogues RSC(BKG)03 R 01, RSC(CGS)02 R 01, RSC(GAOUA)03 R 01 and RSC(AUS)03 R 01 (below BKG, CGS, GAOUAr and AUS), combined catalogue RSC(GAOUA)03 C 01 (below GAOUAc) and ICRF-Ext.1 are given in Table 3.

Table 3: Relative orientation between individual frames, combined catalogue and ICRF-Ext.1. N_d is the number of common defining sources, A_1, A_2, A_3 are the rotation angles (in μas), D_α, D_δ are the drifts in right ascension and declination respectively, B_δ is the bias in declination (in μas/deg for the drifts, μas for the biases).

Frames	N_d	A_1	A_2	A_3	D_α	D_δ	B_δ
BKG–ICRF	191	9±29	-17±29	-10±33	-1±1	-1±1	38±25
CGS–ICRF	175	-3±22	16±22	-7±27	-1±1	-1±0	10±21
GAOUAr–ICRF	211	24±30	20±30	-15±35	-1±1	0±1	-28±26
AUS–ICRF	191	138±45	6±46	-85±51	-3±2	-5±1	205±40
GAOUAc–ICRF	211	13±26	5±26	-22±30	-1±1	0±1	5±24

No significant slopes in RA and Dec and biases were detected in any individual frame except RSC(AUS)03 R 01.

Moreover, the constrains applied to align the respective frames including GAOUAc to ICRF have resulted in agreements of frame orientation at a few tens of microarcsecond (see values in Table 3).

Figures 1 and 2 show, for the defining sources which are common to GAOUAc and ICRF, postfit residuals in RA and in Dec as a function of declination, and their normalized residuals in a plane RA – Dec respectively.

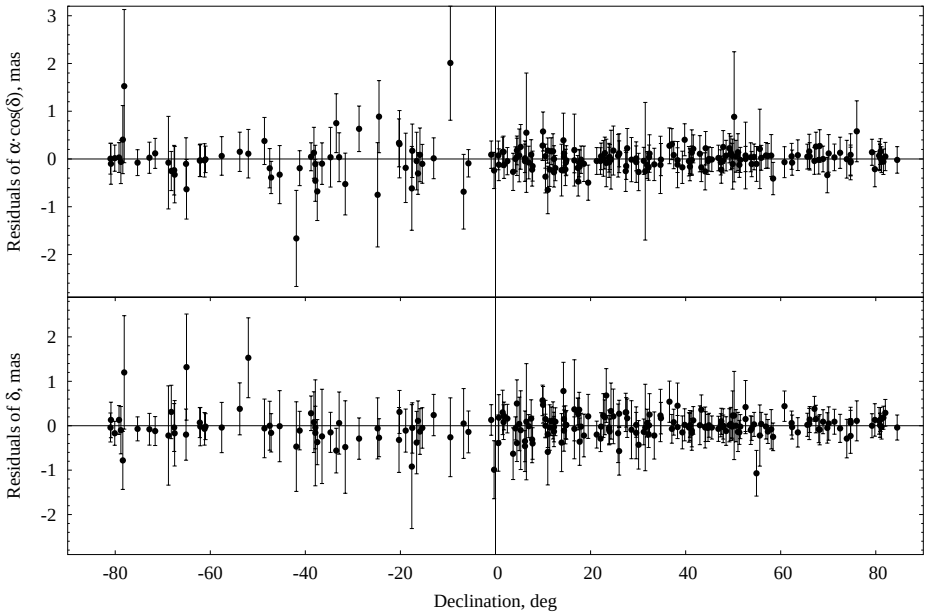

Figure 1: Postfit residuals "GAOUAc–ICRF" against declination for common defining RSs.

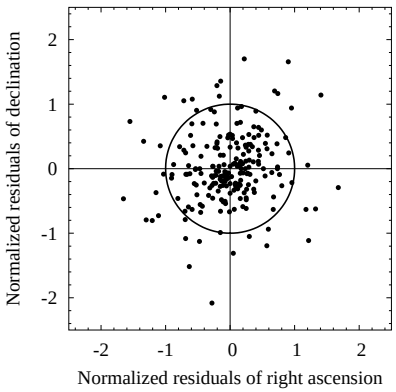

Figure 2: Distribution of normalized residuals "GAOUAc–ICRF" for common defining RSs.

5. ON THE INCONSISTENCIES OF THE GAOUA TYPES OF RS CATALOGUES WITH ICRF-Ext.1

With respect to observational data used for determination of RS positions in ICRF-Ext.1 and RSC(GAOUA)03 R 01 as well as for construction of the combined catalogue RSC(GAOUA)03 C 01 we have to consider that these catalogues are not independent. Thus the comparison between these realizations of the ICRF can not be used as objective quality control.

Nevertheless, we have used the comparison of these three catalogues to determine the so-called "external" estimates of uncertainties for these frames. The following calculations were

made:

a) formal average values of positions of radio sources were derived for different set of individual and combined/compiled catalogues (SO-system);

b) differences $d_{i\circ}$ and $d_{j\circ}$ between positions of i-th and j-th individual frames and SO-system were calculated and used for determination of the coefficient of correlation r_{ij} between i-th and j-th frames.

c) the r.m.s. differences d_{ij} and the correlation r_{ij} between the i-th and j-th frames were used to evaluate the "external" accuracy σ_i of the i-th frame using the following equation

$$d_{ij}^2 = \sigma_i^2 + \sigma_j^2 - 2r_{ij}\sigma_i\sigma_j, \qquad i \neq j$$

Table 4 gives the r.m.s. differences d_{ij}, coefficients of correlation r_{ij} between corresponding frames, and estimated "external" r.m.s. uncertainties σ_i of the ICRF, GAOUAc and GAOUAr frames.

Table 4: "External" estimations of uncertainties of the reference frames. Mean r.s. differences, d_{ij}, correlations, r_{ij}, and the estimated uncertainties, σ_i calculated for all common and for all common defining RSs. Indexes used as follows: 1 - ICRF, 2 - GAOUAc, 3 - GAOUAr.

	r.m.s. differences d_{ij} mas			correlation			uncertainties, mas, on condition $r_{ij} \neq 0$		
	d_{12}	d_{13}	d_{23}	r_{12}	r_{13}	r_{23}	σ_1	σ_2	σ_3
all 584 common RS									
RA	0.54	0.58	0.21	-0.85	-0.89	0.51	0.54	0.06	0.20
Decl	0.61	0.62	0.25	-0.84	-0.86	0.45	0.40	0.23	0.24
211 common defining RS									
RA	0.32	0.34	0.11	-0.86	-0.91	0.57	0.32	0.01	0.12
Decl	0.30	0.38	0.16	-0.73	-0.90	0.37	0.32	0.01	0.19

The data of Table 4 indicate that the internal consistency of the ICRF-Ext.1 could be improved. One of possibility of such improvement is to identify radio sources with large systematic displacements in the ICRF.

Using the set of differences of "Combined frame – ICRF-Ext.1" the large differences in RA and Dec were identified when they were larger than 1 mas (for all common RS) and 0.45 mas (for common defining RS) in three and more catalogues (see Tables 5-6 and 7-8 respectively).

6. CONCLUSIONS

The final conclusions are the following:

1. Constraints applied to align the GAOUA combined catalogues to ICRF have resulted in agreements of frames at a few tens of microarcsecond. No significant slopes and biases in RA and Dec were detected in those of catalogues constructed since 1999.

2. Averaged internal uncertainties of RA and Dec of the GAOUA combined catalogues (since 1999) are less than 0,1 mas and averaged value of the r.m.s. differences of "Combined frame – ICRF" in RA and Dec is about 0,25 mas.

3. The combined catalogue RSC(GAOUA)03 C 01 internally is more consistent as compared with the ICRF-Ext.1.

Table 5: Statistics of large differences in RA for combined catalogues GAOUA and ICRF-Ext.1 – all common RS (Status of the sources: 'D' – defining, 'C' – candidate, 'O' – other radio sources) (in mas).

RS Designation	$\Delta\alpha * \cos\delta$ RSC(GAOUA)					St
	98 C 01	99 C 03	00 C 01	01 C 01	03 C 01	
0138 − 097	2.22	1.63	1.64	2.34	2.01	D
0529 + 075	-1.38	–	-1.31	–	-1.01	C
0823 − 500	-1.48	-1.40	-1.32	-1.67	-7.10	C
1156 − 094	1.42	1.33	1.36	1.11	1.02	C
1323 + 321	-10.74	-1.10	–	-2.36	–	C
1328 + 307	–	-1.01	-0.97	-0.98	-1.30	C
1540 − 828	2.04	2.24	2.44	1.01	–	C
1604 − 333	–	–	0.94	1.08	0.75	D
1733 − 565	–	0.86	0.80	1.30	1.55	C
1740 − 517	-2.57	-1.71	-2.46	–	–	C
1806 − 458	-2.76	-1.93	-0.92	–	-1.39	C
1934 − 638	-1.95	-1.99	-2.30	-1.08	–	C
2128 + 048	–	1.05	0.96	1.02	1.18	O

Table 6: Statistics of large differences in RA for combined catalogues GAOUA and ICRF-Ext.1 – common defining RS (in mas).

RS Designation	$\Delta\alpha * \cos\delta$ RSC(GAOUA)				
	98 C 01	99 C 03	00 C 01	01 C 01	03 C 01
0138 − 097	2.22	1.63	1.64	2.34	2.01
0437 − 454	-0.54	-0.48	-0.47	-0.44	–
0537 − 286	0.40	0.42	0.46	0.51	0.63
0733 − 174	-0.30	-0.52	-0.50	-0.52	-0.62
1143 − 245	–	-0.79	-0.87	-0.90	-0.75
1448 + 762	0.75	0.84	0.88	0.98	0.58
1604 − 333	–	–	0.94	1.08	0.75
1727 + 502	–	–	-0.53	-0.57	0.88

Table 7: Statistics of large differences in Dec for combined catalogues GAOUA and ICRF-Ext.1 – all common RS (Status of the sources: 'D' – defining, 'C' – candidate, 'O' – other radio sources) (in mas).

RS Designation	$\Delta\delta$ RSC(GAOUA)					St
	98 C 01	99 C 03	00 C 01	01 C 01	03 C 01	
$0259+121$	–	4.70	1.25	1.45	1.40	C
$0440-003$	-1.11	-1.25	-1.08	-1.26	-0.99	D
$0454-463$	–	-6.56	-17.97	-16.73	–	C
$0600+219$	–	–	1.18	1.22	2.27	O
$1156-094$	–	0.97	1.03	1.14	1.17	C
$1402-012$	1.04	0.97	0.94	2.47	2.77	C
$1409+218$	–	1.10	0.99	0.91	–	C
$1718-649$	1.06	1.08	–	1.62	1.32	D
$1951+355$	-2.05	-1.89	-1.79	-1.75	-1.28	C
$2312-319$	-0.98	-1.14	-1.19	-0.79	–	D

Table 8: Statistics of large differences in Dec for combined catalogues GAOUA and ICRF-Ext.1 – common defining RS (in mas).

RS Designation	$\Delta\delta$ RSC(GAOUA)				
	98 C 01	99 C 03	00 C 01	01 C 01	03 C 01
$0039+230$	–	–	0.54	0.53	0.68
$0123+257$	–	-0.47	–	-0.68	-0.57
$0131-522$	–	0.71	0.58	–	1.53
$0440-003$	-1.11	-1.25	-1.08	-1.26	-0.99
$0458+138$	-0.76	-0.97	-0.84	-0.85	-0.38
$0518+165$	0.69	0.56	0.48	0.47	0.37
$0733-174$	–	-0.48	–	-0.51	-0.92
$0812+367$	–	0.72	0.71	0.73	0.54
$0829+046$	–	0.52	0.52	0.47	0.50
$1038+064$	-0.60	-0.62	-0.58	-0.54	-0.46
$1616+063$	–	-0.66	-0.61	-0.60	–
$2059+034$	-1.03	-0.76	-0.66	-0.63	-0.63
$2312-319$	-0.98	-1.14	-1.19	-0.79	-0.48

4. There are several RSs which systematically (for more than three catalogues) exhibit large differences of "Combined frame – ICRF" in RA and Dec (larger than one mas). Three of them are the defining sources, namely 0138-097, 0440-003 and 2312-319, which have to be considered as problem sources to be included in the ICRF.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

Bolotin S.L., 2001. Analysis of VLBI observations. Estimation of parameters, Kinematics and Physics of Celestial Bodies, 17, No. 3, Kiev, pp. 240-248.

Bolotin S. Estimation of the Celestial Intermediate Pole motion in the Terrestrial and Celestial reference frames for VLBI observations on the interval 1979 - 2003, this volume.

IVS: International VLBI Service products available electronically at http://ivscc.gsfc.nasa.gov/service/products.

Kur'yanova A.N., Yatskiv Ya.S., 1993. The compiled catalogue of positions of extragalactic radio sources RSC(GAOUA)91 C 01, Kinematics and Physics of Celestial Bodies, 9, No. 2, pp. 15-25.

Yatskiv Ya.S., Kur'yanova A.N., 1990. A new approach to the construction of a compiled catalogue of positions of extragalactic radio sources. – Inertial Coordinate System on the Sky : Proc. 141th IAU Symp., – Leningrad, Kluwer, pp. 295–296.

Yatskiv Ya., Molotaj O., Kur'yanova A. and Tel'nyuk - Adamchuk V., 2003. Recent compiled catalogue of radio source positions RSC(GAOUA)01 C 01. Proc. Journees Systemes de Reference Spatio-Temporels 2002, Astrometry from Ground and Space, Bucharest (Rumania) (in print).